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General Review of Water Quality in Massachusetts

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General Review of Water Quality in Massachusetts and its Relation to National Trends

An Interactive Qualifying Project Report
submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree of Bachelor of Science
by

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Date: **March 3, 2011**

Abstract

This work was an evaluation of the public drinking water quality of different regions of the United States with an emphasis on Massachusetts. Trends observed for the contaminant levels in drinking water, on the state level, were checked against nationwide data to determine correlations. Contaminant levels were seen to depend on population densities and industry. An article was written and is pending publication in the Journal of Hydrology. This study demonstrated that there are observable trends in drinking water quality in the United States as well as Massachusetts.

The results of this IQP have been compiled into a journal article. This article has been submitted to the

Journal of Hydrology, for publication.

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Introduction

The quality of public drinking water is a concern for every citizen. If contaminant levels are not strictly regulated and treated, they could rise to levels that would affect the health of anyone who uses the water. Since water quality should be standard to everyone living in the United States, it was necessary to check if the affluence of a given area had an impact on the quality of the water. It was hypothesized that an area that had a lower income per capita would not have as much resources to regulate water quality as a more affluent town, leading to a decrease in water quality. Prevalent attitude towards public drinking water is that it is easier and safer to buy bottled water, but if this is not the case and the drinking water that is currently available to the public is safe to drink it is a waste of consumer's money to be purchasing bottled water.

Public drinking water quality reports were collected and compiled in order to analyze the data over different regions and temporal periods. In Massachusetts, drinking water quality for over forty towns is regulated and tested by the Massachusetts Water Resources Authority (MWRA), amongst these is most notably Boston. Towns that are covered by the MWRA do not have their own individual data available. The MWRA provides monthly and annual averages of all of the towns that they test for, rather than providing individual data.

The purpose of this study was to determine whether there were any correlations between drinking water quality and socioeconomic regions. Through the analysis of public water quality reports, it was observed that the affluence of a given region had almost zero affect on the drinking water quality. During this analysis it was observed that the population density and the industry of a region do in fact play a role in the drinking water quality. These trends that were initially observed on a state level in Massachusetts were examined in cities across the nation, because of the scope of the MWRA Boston could not be included, and at a nationwide level.

Objectives

This work aims to complete the following objectives:

1. Establish preliminary research into water quality guidelines and regulations.

    a. Determine maximum contaminant levels for Massachusetts.

        i. Determine Environmental Protection Agency standards

        ii. Determine Massachusetts Water Resources Authority regulations

    b. Determine maximum contaminant levels for the United States.

    c. Compile annual water quality reports from various towns, cities, and states.

2. Establish the importance of water testing and treatment.

    a. Determine the potential health effects of contaminants that exceed the maximum levels.

    b. Research treatment techniques for public drinking water.

3. Analyze data to determine trends in drinking water quality.

    a. Establish trends in Massachusetts in drinking water quality

    b. Establish trends on a national level in drinking water quality

4. Compile data into a journal article.

    a. Submit article to scientific journal for publication

Methodology

The purpose of this project was to analyze the water quality of the United States with a particular emphasis on Massachusetts, and to determine if any observable trends could be seen. In order to accomplish this, research of several years' worth of water quality reports was conducted and the data from these reports was compiled and analyzed. Several tests to determine total coliform levels in water samples from various towns across Massachusetts were done in the Civil Engineering Lab in Kaven Hall in addition to the initial research; the procedure for these tests is described below.

Several towns in Massachusetts have their annual water quality reports published and available on their official town websites. However most do not have that information readily available and instead rely on the Massachusetts Water Resources Authority (MWRA) for their testing and compiling of results. Therefore data for Massachusetts was obtained from the published MWRA reports. The data for all of the other States in the U.S. was obtained from a Consumer Confidence Report (CCR) published by the United States Environmental Protection Agency.

The testing performed in in the Civil Engineering Lab in Kaven Hall was done to affirm the results of the published data regarding the detection of coliform bacteria in public drinking water samples. Water samples were collected in a sterile 250 mL container which was pretreated with a de-chlorinating agent. The samples were collected from the town halls of several cities and towns in Massachusetts; Newton, Weston, Sudbury, Revere, Lynn, and Worcester, as a representative sample of public drinking water. A nutrients agar was introduced into each of the water samples to allow for bacteria growth and then the samples were incubated for a period of 24 hours at a temperature of 30°C. The samples were then analyzed to determine the levels of bacteria present in them.

The results of both the research and lab tests were then compiled into a journal article. Several Journals were initially contacted to examine the appropriateness of the topic. These journals included the **Journal of Hydrology**, **Science of the Total Environment**, and **STOTEN**. Email correspondences from these journals are attached in Appendix B. Based on email response it was decided to submit the article to the **Journal of Hydrology** for publication. Presented in the following sections is the complete paper submitted for review.

Paper Submitted to **The Journal of Hydrology**

General review of water quality in Massachusetts and its relation to national trends

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Abstract

This work is an evaluation of the water quality of different regions of the United States with an emphasis on Massachusetts. The criteria investigated for the determination of water quality were trihalomethanes, haloacetic acids, nitrates, lead, copper, hardness, total chlorine, and turbidity. Higher number of violations of the limits of these contaminants was seen to occur in the Northeastern and Southern regions of the country. The higher number of violations can be attributed to higher population densities in these regions and the type of industry local to the area. This trend was also observed in the towns of Massachusetts.

1. Introduction

There are several regional and economic factors that contribute to the differentiations in water quality across the country. Population density and industry were seen to have a correlation with drinking water quality. The type and size of industry in a region will often dictate the type of contaminants that will be found in the water. This can cause problems in area with large chemical or petroleum industries. Areas with large population densities were also observed to have an increased level of violations and can also be associated with larger industrialization in the region.

The EPA sets regulatory standards on all contaminants found in public drinking water (Table 1). All states must comply with these established levels and report when these levels exceed the limits. In many cases there are a large number of violations of these limits every year. This can potentially be dangerous because many of the contaminants can cause health problems. The contaminants that were examined in this report were: haloacetic acids, trihalomethanes, turbidity, total chlorine, lead, and copper.

All of these contaminants carry with them some potential concerns. Both trihalomethanes and haloacetic acids, which are disinfection by-products from chlorine interacting with organic compounds (Legay et al., 2010), have been linked to an increased risk for both rectal and bladder cancer (Simpson and Hayes, 1996). Turbidity is not dangerous itself but can be a potential warning sign that other contaminants, such as bacteria are present. Lead has been known to cause cancer, nephrotoxicity, central nervous system effects, and cardiovascular disease in humans (Ryan et al., 2000). High levels of copper have been linked to acute gastrointestinal problems, such as, nausea, vomiting and diarrhea (Lagos et al., 1999). Total coliform is not itself dangerous but high levels may be an indicator that more dangerous strains of coliform such as fecal coliform or E. coli are present. E. coli causes several gastrointestinal problems such as bloody diarrhea and hemolytic uremic syndrome (Soller et al., 2010).

Currently in Massachusetts, the majority of drinking water quality testing is regulated solely by the Massachusetts Water Resources Authority (MWRA). The MWRA is responsible for testing and distributing the results for over forty towns in the state. These towns usually do not have access to their own testing results besides what the MWRA provides.

Within the state of Massachusetts it was hypothesized that there would be a measurable difference in the water quality of different socioeconomic regions. It was believed that lower income areas would have lower budgets for the maintenance and testing of public water systems and therefore would cause the quality of the water to be subpar. Looking into the budget allocations for towns in Massachusetts it was inconclusive as to how much money each town allocated to the maintenance and testing of water. Each town would invariably break the budget down to how much money they would give to their public works division, but would not go further to mention where the public works organization planned to distribute the money. Since it was not possible to uncover where the funds of these towns were allocated through public records; it was decided to see if there was a noticeable difference between drinking water qualities in the different socioeconomic conditions through empirical data. In actuality all towns are strictly monitored by the MWRA, and the contaminant levels in the drinking water fell within the acceptable ranges set forth by the EPA.

The quality of drinking water is a concern for all citizens and something that most take for granted. It is generally assumed that all drinking water from public systems is safe, and in some cases this is not true. The focus of this study is to determine just how safe drinking water is and if there are regional factors that affect its quality. These regional differences were examined on both the national and state level, with an emphasis on Massachusetts.

2. Methodology

2.1 Data Review

The contaminant levels of four additional towns were compared using their annual water quality reports for analysis. These towns were chosen based on their level of industrialization, population densities, and their income per capita. The city of Worcester has a high level of industrialization, population density of 4,678.1/sq mi, and a medium per capita income of $24,213. Lynn is moderately industrialized, with a high population density of 8,066.9/ sq mi and a low per capita income of $20,944. Lowell was chosen for its moderate level of industrialization, a high population density of 7,500.9/sq mi, and a low income per capita of $22,831. Sudbury was also chosen for its rural atmosphere, a small population density of 703.2/ sq mi, and a high per capita income of $56,050. Hudson has a low level of industrialization, a population density of 1,702.6/sq mi, and a medium per capita income of $33,944. Cambridge has a high level of industrialization, a high population density of 16,422.08/sq mi, and a median per capita of $44,171. Amesbury was chosen for its low industrialization level, a low population density of 1,889.9/sq mi, and a medium per capita income of $35,583. The per capita income and population densities were obtained by data published by the United States Census Bureau and accessed using the American fact finder.

Water quality levels were obtained from 2009 annual water quality reports from the states, cities, and towns of interest (Massachusetts Water Research Authority [MWRA], 2003b-2009). All reports were governed by the EPA standards. Additional research was performed to assess the risks associated with the excess levels of the different contaminants.

3. Results and discussion

3.1 Analysis of different towns in Massachusetts' water quality.

Several towns in Massachusetts were analyzed for their drinking water quality. The data was collected from the perspective town's annual drinking water quality reports for the year 2009. These towns were selected for this analysis on the basis that they do their own testing apart from that of the MWRA. The towns whose water quality was being analyzed are all located in the general area of the northern and central eastern Massachusetts; however, they vary in population density and their relative affluence. Fig. 1 shows the results for the analysis for a variety of contaminants.

As seen in the figure, all of the towns were within the maximum contaminant level, with the exception of Sudbury's turbidity level. Even though the contaminant levels for all of the towns fell under the legal limits, there was still a considerable amount of variation between the towns. Hudson, which is a rural town with a low population density, had the highest levels of trihalomethanes, haloacetic acids, and copper. Cambridge, which is a large city in Massachusetts, only showed high levels of lead and total chlorine, and significantly lower levels of the other contaminants. The hypothesis was that larger town's with high population densities and that were more industrialized would show higher contaminant levels. The data for these towns in Massachusetts does not support this hypothesis. Small rural towns were seen to have higher levels of contaminants than some cities. The contaminant levels were still under the legal limits established by the EPA; this shows that the state of Massachusetts is successfully regulated and that water treatment facilities in the state are successful in their treatment.

In Fig. 1, there are some trends that can be seen, when the towns are ordered in increasing population density. For the trihalomethane, haloacetic acid, turbidity, and copper levels the amount of contaminants almost linearly decreases as the population density increases. The opposite effect can be seen for the total chlorine and lead levels, as population density increases so do these contaminant levels. This shows that the public drinking water quality in a given area could be dependent on the population density.

3.2 Analysis of Massachusetts water quality reported by the MWRA.

The MWRA data for the disinfection by-products (trihalomethanes and haloacetic acid) shows a drastic reduction in their quantity in drinking water beginning around 2005 shown in Fig. 2. For the trihalomethane content of the water this reduction could not have come at a better time, since the MWRA water quality readings in 2005 shows the end of a trend that nearly brought the trihalomethane content above the EPA standards. The reason for this decrease is because starting in 2005 the MWRA introduced a new method of water disinfection that reduced the amount of chlorine necessary to kill the bacteria in the water (MWRA, 2003a). The new method of disinfection now makes the title of disinfection by-products, for trihalomethanes and haloacetic acid, something of a misnomer. Now with the new system the water can be disinfected without introducing as much chlorine, the chlorine that would then bind to organic compounds in the water and produce the trihalomethanes and haloacetic acid.

Lead concentrations in drinking water showed a steady decline from a value of 17.1 parts per billion (ppb), exceeding the EPA's maximum contaminate level (MCL) allowed in drinking water, and finally lowering below the EPA standards in 2004. In addition to this decrease the lead concentration experienced a larger decrease starting in 2006 that can also be attributed to the lowered requirement of chlorine for the disinfection process in the water treatment. The chlorine creates an acidic environment that was used to kill the bacteria in the water; however it also had the side effect of corroding the pipes that carry the water and with some of the pipes still composed of lead this corrosion stripped the lead from the pipes and left it in the water (Cantor, 2000).

The variation of copper concentrations showed a similar trend to the lead levels in the drinking water on a much smaller scale, this is because the same process that strips the lead out of the pipes also strips copper from the sections of the water distribution lines that are made of copper. The lower levels of chlorine and thus the more basic water conditions led to a decline in the copper levels in the drinking water starting in 2005 (Cantor, 2000). The muted variation of the copper quantities in the water is due in part to the hardness of the water. Massachusetts water is comparatively softer than most water; however, over time the magnesium and calcium deposits in the water, causing the hardness, build up on the copper pipes causing less copper to be stripped even in acidic conditions.

Nitrate levels reported by the MWRA come in substantially lower than the maximum levels. Massachusetts does not employ much agriculture. Consequently nitrate levels in drinking water are low, and while nitrates are found naturally, in order to have levels reaching the MCL it is necessary that the majority of the nitrate comes from the intervention of humans. For the most part this unintentional introduction of the nitrates comes from fertilizer used on farms running out of the soul and seeping into the drinking water sources. In order to have high statewide levels of nitrogen it is mainly necessary to have a large agriculture industry.

3.3 Analysis of drinking water quality for major cities in the United States.

The contaminant levels in public drinking water for eight major cities in the United States were analyzed. The additional study was done to test whether the trends seen in Massachusetts were exhibited throughout the United States. The cities being studied were gathered from various regions in the United States and at varying population densities. An increasing trend could be seen in the turbidity and lead contaminant graphs seen in Fig. 3. As population density increased, so did the levels of these contaminants. The lead analysis for town's in Massachusetts had the same correlation, yet the turbidity levels had the opposite trend. For the majority, the analysis based on cities in the United States does not show trends similar to that seen in Massachusetts. The location, degree of industry, climate, and treatment facilities that differ between the cities are more likely the cause of the variance of contaminat levels rather than the population densities. In Massachusetts, the location and climate were fairly constant between the towns that were chosen, leaving less variables between locations.

3.4 National trends of violations of water quality rules.

In order to determine a relationship between water quality and region it was first necessary to break the United States up into four regions. The four regions are the Northeast, South, Midwest, and West. The United States Census Bureau defines the boundaries of these regions and within these areas are several sub-regions. The criterion for comparison in this analysis was the total number of violations in a given year for each state. The total number of violations is the sum of violations of several different standards and rules set by the EPA. These include violations of the Chemical Contaminant Group, Total Coliform Rule, Surface Water Treatment Rule, Interim Enhanced Surface Water Treatment Rule, Filter Backwash Recycling Rule, Lead and Copper Rule, and the Disinfectant Byproducts Rule. As discussed previously the EPA sets standards on the amounts of contaminants, and exceeding those limits constitutes in a violation of one of the rules listed here.

For the years 2007 and 2008 an emerging trend can be seen for violations in the United States. When analyzing simply state by state there is no real correlation to be made, however when looking at each region as a different piece of the country some trends can be observed Fig. 4. In both the Northeastern and Southern regions of the country, on average, the total numbers of violations are relatively close, around 3,500 violations per year. However, examining the average number of violations of both the Midwest and West, a measurable difference can be observed. Both of these regions on average had roughly 2,000 violations a year, meaning a 40%

decrease as compared with the Northeast and South. There are several factors that could cause a particular region of the United States to have superior drinking water and another area to be slightly inferior.

One such reason for the larger number of violations in the Northeast and South could simply be due to population density. It can be seen in Figure 4 that both the Northeast and South have a significantly higher population density as compared with the Midwest and Western regions of the United States. It would be expected that a larger number of people living in a significantly smaller region of the United would cause a greater number of violations. The increased density means that there must be a larger number of public water systems in this region to adequately provide drinking water to the population. It would be expected that with a greater number of systems to monitor and maintain, violations would happen more frequently. Based on these assumptions, it can be expected that the state of Alaska is likely to have the lowest number of violations; however this example demonstrates another important factor that affects water quality, so here it is necessary to take into account the type of industry in the area. The concentration and type of industries in an area are also reasons for an increased number of violations, specifically in the chemical contaminant group. As a whole the Midwest to Western areas of the country tends to be less industrialized, whereas the northeast and southern areas tend to have larger areas of industry. Going back to Alaska, as an example, a lot of the industry is based on oil, and the oil industry can have negative impacts on the environment, thereby accounting for the increased number of violations in a region with relatively low population density. Another example of industry affecting quality of drinking water may also be seen with the case of Texas. Texas is another state that is well known for its oil industry and which also has a higher than average population density, and the state, on average, has more violations in a given year than other states. Similar to Texas is the state of Pennsylvania, being the 11^{th} most densely populated state. Pennsylvania is also big in the fossil fuel industry; they are the leading producer of coal in the United States. Coal has the reputation of being a dirty source of fuel, and could thusly negatively impact the quality of the drinking water in the state.

4. Conclusions

Analyzing the national trends it was determined that having both high population density and industrialization in a region will lead to higher water contamination levels. This is demonstrated by the higher contaminant levels in the Northeastern and Southern sections of the United States where there is high population density and an abundance of chemical and petroleum plants. On the state level noticeable trends occurred for the types and levels of contaminants based on the predominant industry of the state, and large scale changes in water management, shown by the low levels of nitrates in Massachusetts water and the reduction in lead concentration respectively. On the town level, there were noticeable trends in the overall levels of contaminants with respect to population density. While affluence did not have the effect on water quality that was expected the definite trends at the national and state levels show that depending on what the prevailing industry and the level of population density is for a region, it will have an effect on the quality on the drinking water.

Acknowledgements

This study was supported by Worcester Polytechnic Institute under the guidance of Professor Satya Shivkumar, Worcester, MA 01609, USA.

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Appendix

Table 1: Contaminants and their max contaminant levels set forth by the EPA.

Contaminant	**Maximum Contaminant Level (MCL)**
Haloacetic Acids	60 ppb
Trihalomethanes	80 ppb
Turbidity	1 NTU
Total Chlorine	4 ppm
Lead	15 ppb
Copper	1.3 ppm
Total Coliform	5% positive

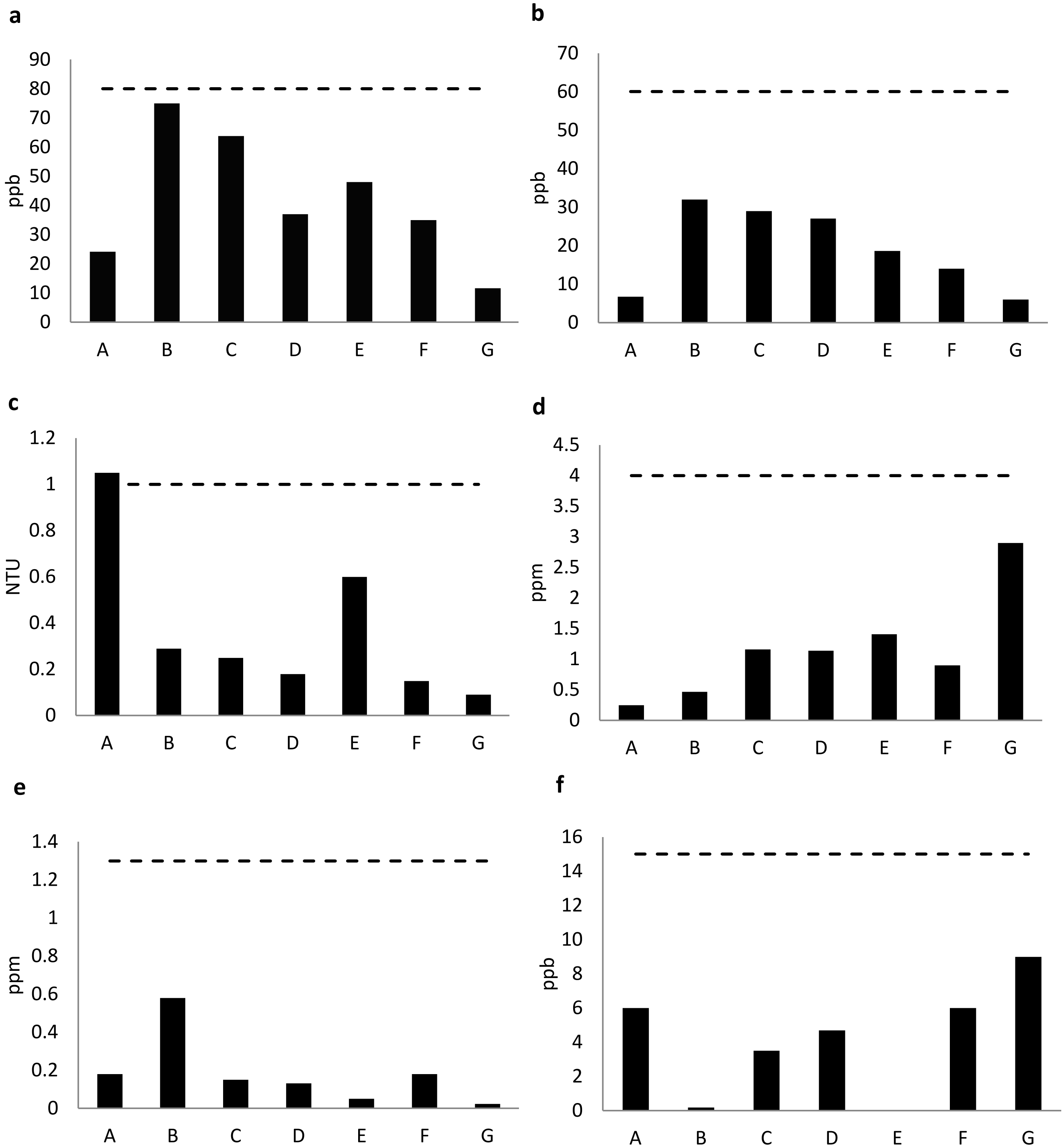

Figure 1: Highest recorded contaminant levels for seven towns in Massachusetts; Towns are ordered in increasing population density (A) Sudbury, (B) Hudson, (C) Amesbury, (D) Worcester, (E) Lowell, (F) Lynn, (G) Cambridge. **a**, Trihalomethane levels **b**, Haloacetic acid levels **c**, Turbidity levels **d**, Total Chlorine levels **e**, Copper levels **f**, Lead levels. The maximum contaminant level (MCL) is depicted by a dashed line. Any levels recorded above this line are in violation of the EPA standards.

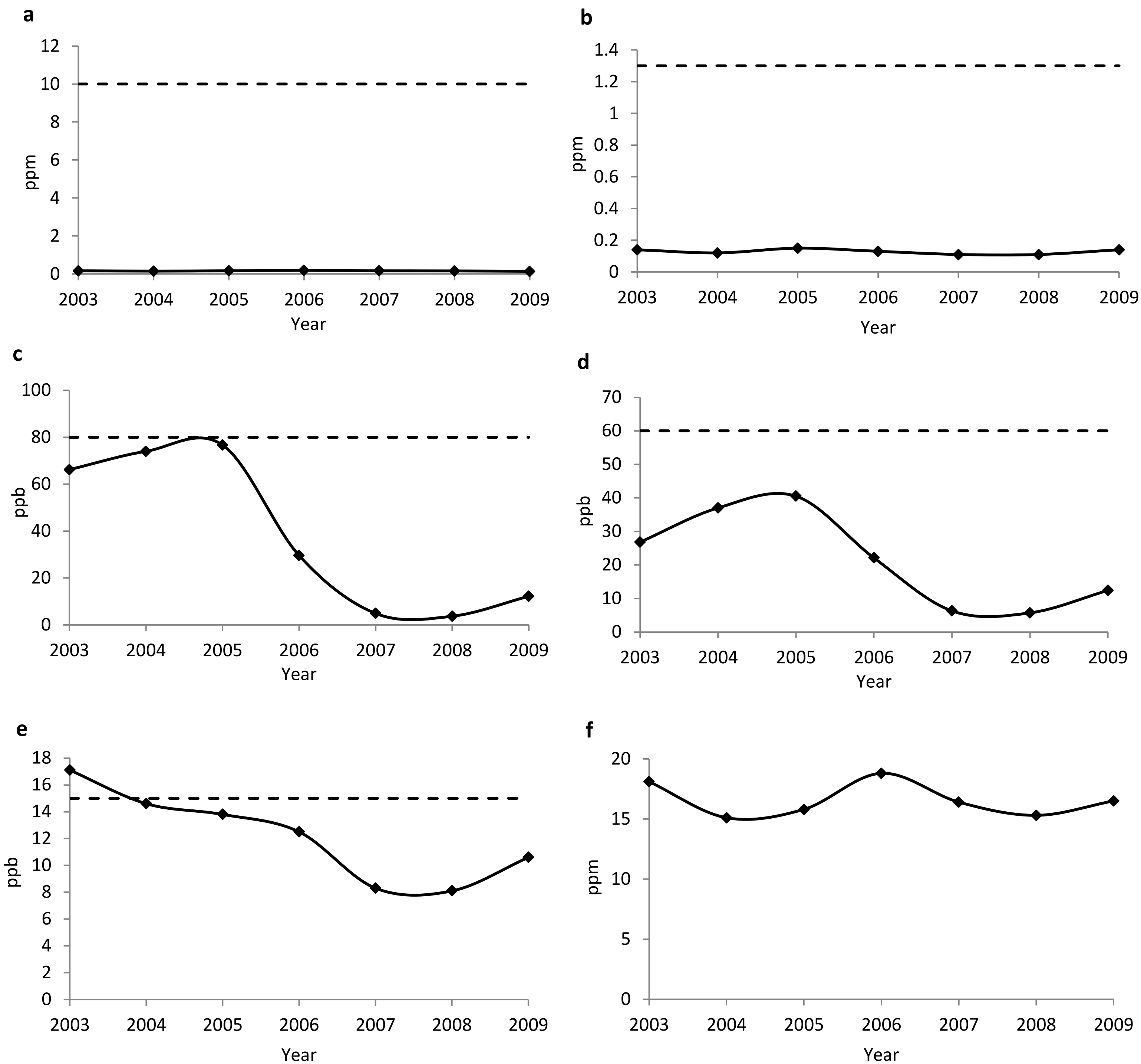

Figure 2: Annual average contaminant levels provided by the MWRA over a period of seven years. **a**, Nitrate levels **b**, Copper levels **c**, Trihalomethane levels **d**, Haloacetic acid levels **e**, Lead levels **f**, Hardness levels. In the graphs (**a-e**), the maximum contaminant level (MCL) is depicted by a dashed line. Any levels recorded above this line are in violation of the EPA standards.

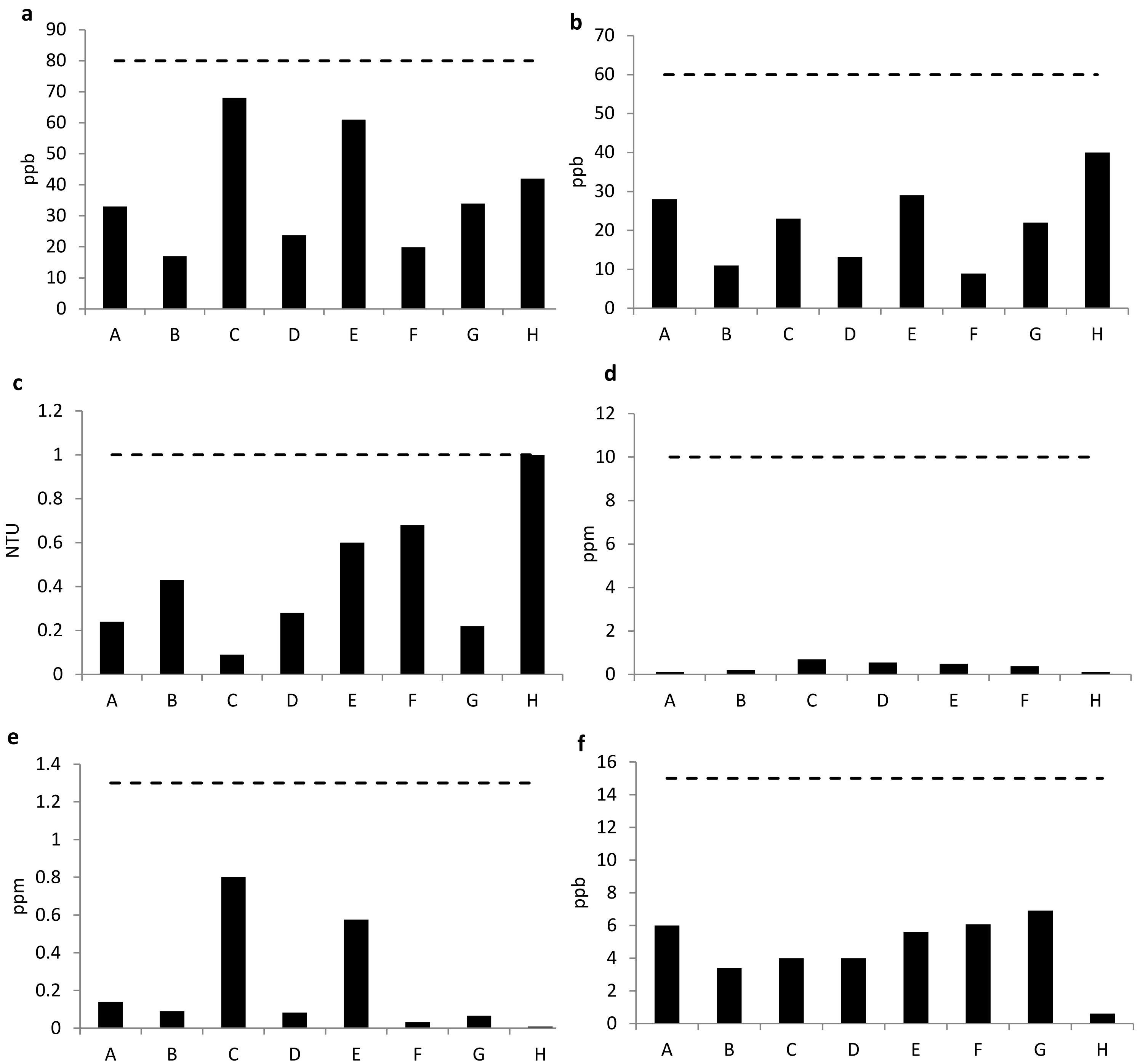

Figure 3: Average recorded contaminant levels for eight major cities in the United States, the cities are ordered in increasing population density; (A) Seattle, (B) Houston, (C) Las Vegas, (D) Detroit, (E) Las Angeles, (F) Chicago, (G) San Francisco, (H) New York City. **a**, Trihalomethane levels **b**, Haloacetic acid levels **c**, Turbidity levels **d**, Nitrates levels, no data was provided by San Francisco for Nitrate levels **e**, Copper levels **f**, Lead levels. The maximum contaminant level (MCL) is depicted by a dashed line. Any levels recorded above this line are in violation of the EPA standards.

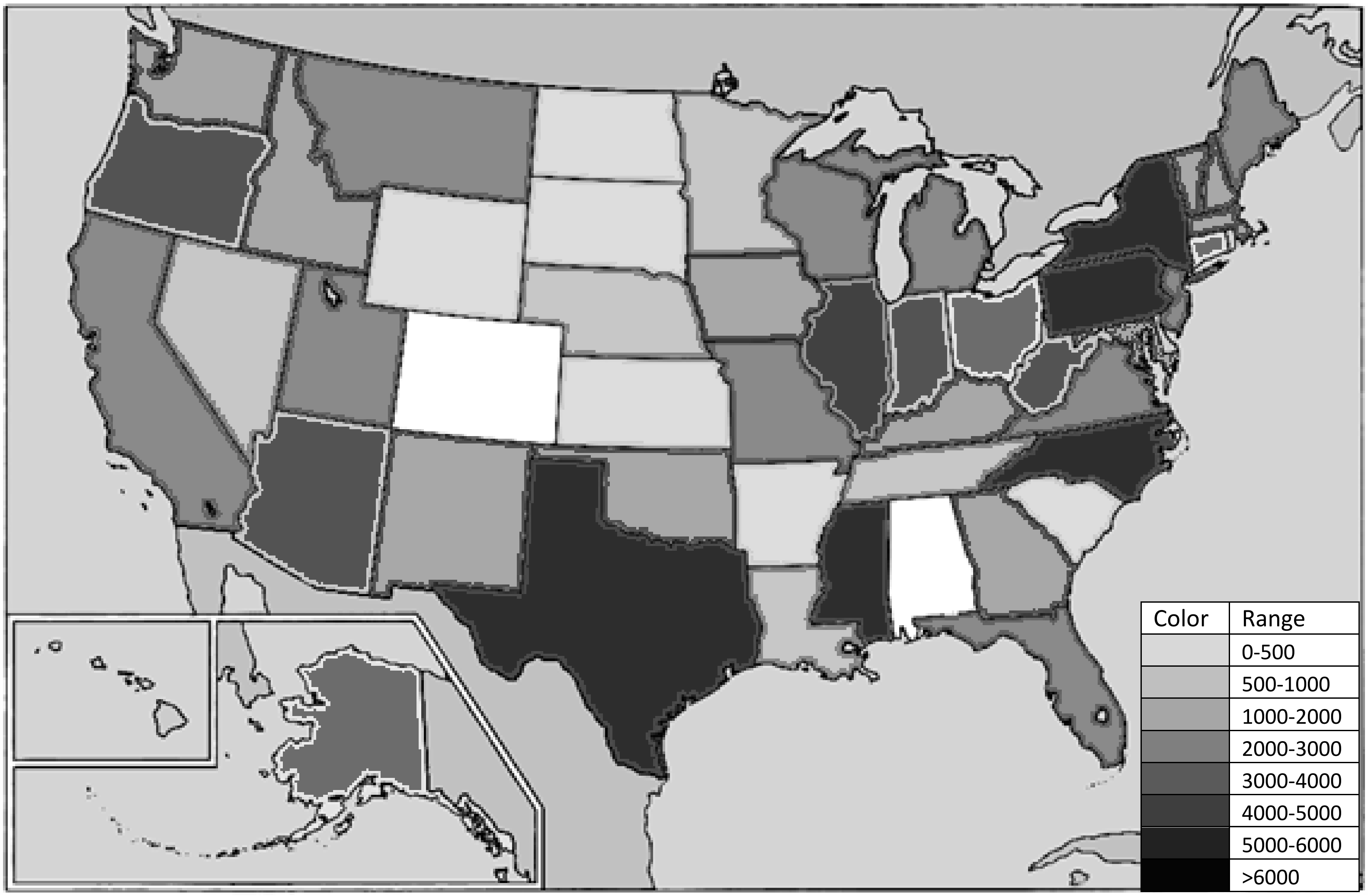

Figure 4: Map of United States depicting the number of water quality violations in the years 2007-2008. Data was not provided for Colorado or Alabama.

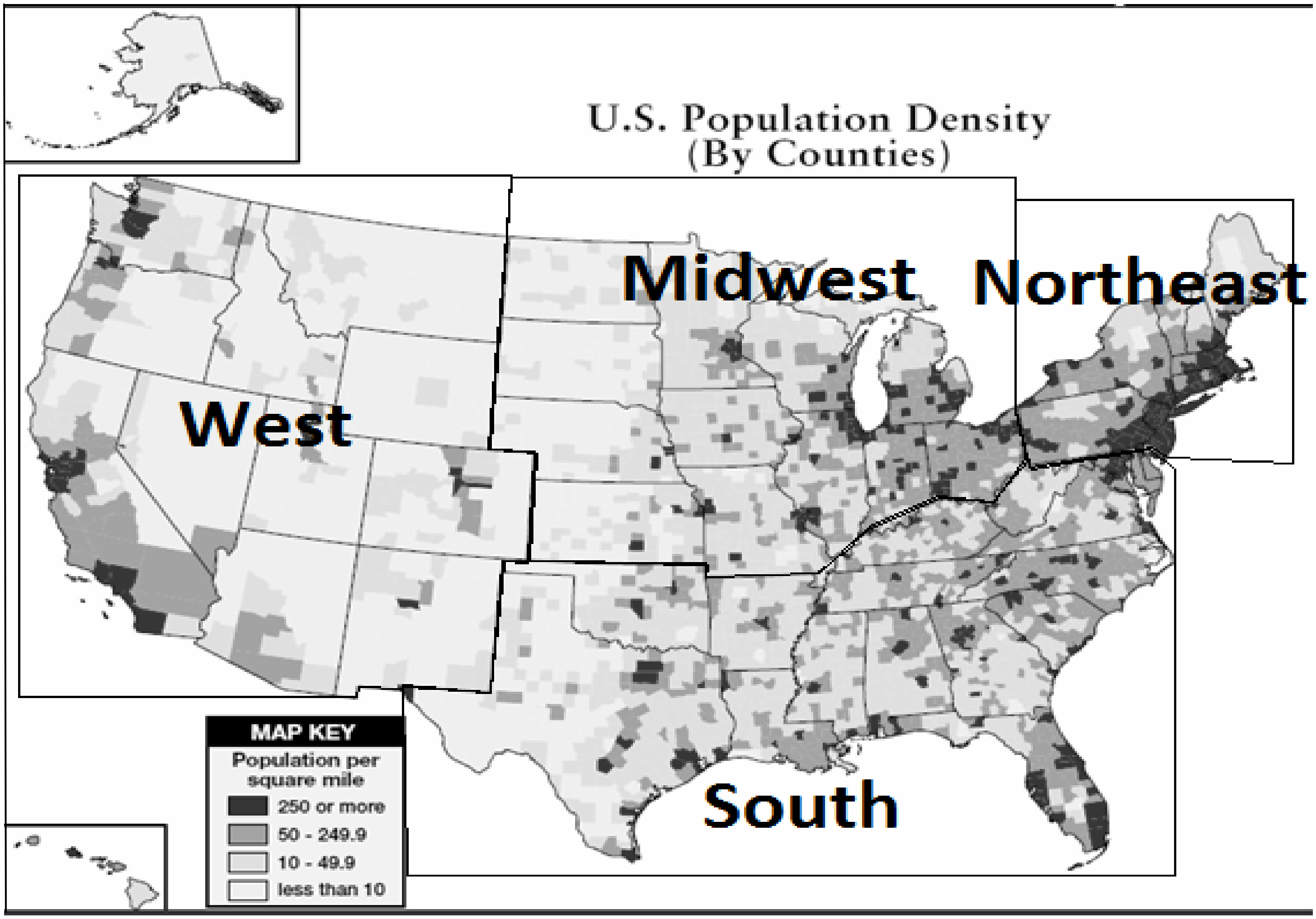

Figure 4: United States population densities provided by the US Census Bureau (U.S. Census Bureau, 2010).

Appendix A

Email correspondence to a town regulated by the MWRA:

Mon, 12/06/2010 5:00 PM

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Dear Mr. Hoffman,

Is there a comprehensive water quality report for the city of Weston, MA,
containing average contaminant levels observed in the water, other than
the one from the MWRA that is provided on the town website? My colleagues
and I are researching several MA towns and are trying to compile data from
Weston.  We hope you can help us out and look forward to hearing from you.

Thank You,
Kyle Goodsell
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Tue, 12/14/2010 1:38 PM

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Hi Kyle:

Our water is tested by the MWRA and thus we don't do any other testing.

Robert L. Hoffman
Director of Operations
Weston Department of Public Works
190 Boston Post Road By-Pass
Weston, MA 02493
781-893-1263 ext.11
781-899-5690 (fax)
hoffman.r@westonmass.org
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Appendix B

Email correspondence with various journal editors:

Email correspondence to editor of STOTEN Journal:

Mon, 9/27/ 2010 2:35 PM

Dear Mr. Nriagu :

This letter is in regard to submitting an article to your journal. We are a group of students from Worcester Polytechnic Institute, in Massachusetts, working on a project about the comparison of tap water from different regions of Massachusetts. Our group consists of two juniors, a biotechnology major and a chemical engineering major, and a senior, also a chemical engineering major. The research we are conducting is also being advised by one of our professors.

Our goal is to test the drinking water from different socioeconomic regions of Massachusetts for their contaminant levels. One of our ultimate goals is to have our research published in a respectable journal such as your own. If this topic sounds like a suitable fit for your journal we would appreciate it if you let us know. We would like to thank you for taking the time to read this proposal and look forward to hearing from you soon.

Thank You,

Kyle Goodsell

Michael Chase

Michael Hoyt

Thu 9/30/2010 2:44 PM

Hello Kyle:

Your study sounds really interesting. Unfortunately, STOTEN now assigns low priority to papers on baseline monitoring of pollutants. With a rejection rate of over 75%, STOTEN is placing emphasis on papers that deal with more cutting-edge research.

I am sure you will find another venue for your work,

Jerome Nriagu, PhD, DSc
Editor-in-Chief

Email correspondence to editor of Environmental Science and Policy Journal:

Wed 3/2/2011 7:12 PM

Dear Editor Briden:

This letter is in regard to submitting an article to your journal. We are a group of students from Worcester Polytechnic Institute, in Massachusetts, working on a project about the comparison of tap water from different regions of Massachusetts. Our group consists of two juniors, a biotechnology major and a chemical engineering major, and a senior, also a chemical engineering major. The research we are conducting is also being advised by one of our professors.

Our goal is to test the drinking water from different socioeconomic regions of Massachusetts for their contaminant levels. One of our ultimate goals is to have our research published in a respectable journal such as your own. If this topic sounds like a suitable fit for your journal we would appreciate it if you let us know. We would like to thank you for taking the time to read this proposal and look forward to hearing from you soon.

Thank You,

Michael Hoyt
Kyle Goodsell
Michael Chase

Mon 10/04/ 2010 10:26 AM

Dear Dr. Hoyt,

I have just received your message via the Oxford Editorial Office.

I would like to stress the fact that our Journal encourages interdisciplinary submissions with a strong policy component. It is a bit difficult on the basis of your message to see what balance you will ultimately strike between the scientific aspects of your paper and the policy relevance of your research. Perhaps the easiest is to submit the paper when it is ready and I will assign an editor who will see whether the submitted manuscripts fits within the aims and scope of ESP. If so, it would then be sent out for review.

Kind regards,

Martin Beniston
Editor-in-Chief, "Environmental Science and Policy"
--
Prof. Martin Beniston
Director, Institute for Environmental Sciences
University of Geneva, Switzerland
Martin.Beniston@unige.ch
www.unige.ch/climate

Email correspondence to editor of Hydrology Journal:

Wed 3/2/2011 4:51 PM

Dear K.P. Georgakakos:

This letter is in regard to submitting an article to your journal. We are a group of students from Worcester Polytechnic Institute, in Massachusetts, working on a project about the comparison of public drinking water from different regions of Massachusetts and how it relates to national trends. Our group consists of two juniors, a biotechnology major and a chemical engineering major, and a senior, also a chemical engineering major. The research that was conducted was also being advised by one of the professors of the Mechanical Engineering Department.

Our article emphasizes trends that were seen between population densities and industry and their affect on the drinking water quality. One of our ultimate goals is to have our research published in a respectable journal such as your own. If this topic sounds like a suitable fit for your journal we would appreciate it if you let us know. We would like to thank you for taking the time to read this proposal and look forward to hearing from you soon.

Thank You,
Kyle Goodsell, Michael Hoyt, Michael Chase

Appendix C

Raw data tables used to create journal figures:

	Nitrates	Copper	Lead	THM	HAA	Turbidity	
Seattle	0.11	0.14	6	33	28	0.24	A
Houston	0.2	0.09	3.4	17	11	0.43	B
Vegas	0.7	0.8	4	68	23	0.09	C
Detroit	0.55	0.083	4	23.7	13.2	0.28	D
LA	0.5	0.576	5.6	61	29	0.6	E
Chicago	0.384	0.032	6.07	19.9	8.94	0.68	F
San Francisco	N/A	0.066	6.9	34	22	0.22	G
NYC	0.13	0.009	0.6	42	40	1	H
	d	e	f	a	b	c	
MCL	10	1.3	15	80	60	1	

Nitrate		Trihalomethanes		Chloride		Lead	
Year	Level(ppm)	Year	Level(ppb)	Year	Level(ppm)	Year	Level(ppb)
2003	0.17	2003	66.2	2003	42	2003	17.1
2004	0.15	2004	74	2004	23.4	2004	14.6
2005	0.17	2005	76.7	2005	28.9	2005	13.8
2006	0.2	2006	29.6	2006	33.9	2006	12.5
2007	0.17	2007	4.9	2007	26.4	2007	8.3
2008	0.16	2008	3.7	2008	31.1	2008	8.1
2009	0.14	2009	12.2	2009	34.2	2009	10.6
MAX	10	MAX	80	MAX	250	MAX	15

Hardness		Halo Acetic Acids		Copper	
Year	Level(ppm)	Year	Level(ppb)	Year	Level(ppm)
2003	18.1	2003	26.8	2003	0.14
2004	15.1	2004	37	2004	0.12
2005	15.8	2005	40.5	2005	0.15
2006	18.8	2006	22.1	2006	0.13
2007	16.4	2007	6.3	2007	0.11
2008	15.3	2008	5.7	2008	0.11
2009	16.5	2009	12.4	2009	0.14
MAX		MAX	60	MAX	1.3

Turbidity(NTU)		Lead(ppb)		Copper(ppm)	
Worcester	0.18	Worcester	4.7	Worcester	0.131
Max	1	Max	15	Max	1.3
Sudbury	1.05	Sudbury	6	Sudbury	0.18
Lynn	0.15	Lynn	6	Lynn	0.18
Lowell	0.6	Lowell	0.042	Lowell	0.05
Hudson	0.29	Hudson	0.18	Hudson	0.58
Cambridge	0.091	Cambridge	9	Cambridge	0.023
Amesbury	0.25	Amesbury	3.5	Amesbury	0.15
Total Chlorine(ppm)		Total Trihalomethanes(ppb)		Haloacetic Acids(ppb)	
Worcester	1.14	Worcester	37	Worcester	27
Max	4	Max	80	Max	60
Sudbury	0.25	Sudbury	24.1	Sudbury	6.69
Lynn	0.9	Lynn	35	Lynn	14
Lowell	1.41	Lowell	48	Lowell	18.6
Hudson	0.47	Hudson	75	Hudson	32
Cambridge	2.9	Cambridge	11.6	Cambridge	6
Amesbury	1.16	Amesbury	63.8	Amesbury	29